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# The effects of extensive rapid aiming practice on young adults, older adults, and Parkinson's patients

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# The effects of extensive rapid aiming practice on young adults, older adults, and Parkinson's patients

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## ABSTRACT

The purpose of this study was to investigate the effects of long-term practice on a rapid aiming movement in young adults, older adults and adults with Parkinson's disease (PD). Seven participants in each group engaged in eight practice sessions per week for three weeks; retention was measured weekly for three weeks post-practice. There were two conditions, a low accuracy (large target) condition, which emphasized ballistic processes and a high accuracy (small target) condition, which emphasized online controls. When accuracy requirements were minimal all three groups decreased movement time by decreasing both time to peak velocity and time after peak velocity, and these improvements were retained. Only the neurologically healthy groups increased peak velocity with practice. All three groups also decreased variability of peak velocity and time to peak velocity, and variability continued to decrease during retention. Percent of time spent in the first submovement also increased with practice in all three groups, but none of the groups retained this change during retention. Even with three weeks of practice, group differences were maintained, with the young adults exhibiting faster times, higher peak velocity and lower variability and the adults with PD exhibiting the slowest times, lowest peak velocity and greatest variability. The high accuracy condition yielded few changes with practice. Movement time did not significantly decrease, although, interestingly, all three groups exhibited an increase in percent of time in the first submovement with practice; however, as in the low accuracy condition, this change was not retained by any of the groups. Performance in the high accuracy condition that was most impacted by practice was variability; both variability of peak velocity and time to peak velocity decreased with practice in all three groups, and continued to decrease during retention. There were few group differences in the high accuracy condition; the older adults were faster than those with PD and the young adults exhibited a higher peak velocity than the older adults. Overall, these results indicate that aiming movements that require high accuracy minimize both aging effects and the effects of PD; in contrast, low accuracy movements that are fast and ballistic emphasize both aging and the effect of PD. And, while practice clearly improves ballistic performance, practice does not eliminate the effects of aging and PD. The aspect of control that changed in all groups for both high and low accuracy movements was variability of first force impulse, which continued to decrease throughout retention. Finally, it is noted that all groups retained improvements with practice, including those with PD.

# INTRODUCTION

Aiming movements are used to complete various actions that require accurate limb trajectory, such as reaching. Reaching is a basic component of many daily activities. Thus, accurate aiming is an important skill for daily living.

The study of aiming movements in neurologically healthy individuals provides insight into the mechanisms that control this movement. In addition, insights can be gained from people with central nervous system (CNS) damage who have difficulty producing aiming movements. The purpose of this study is to examine rapid aiming movements in neurologically healthy young and older adults and people with Parkinson's disease (PD).

Woodworth (1899) was the first to examine rapid aiming movements. His interest in rapid aiming came from observation of construction workers repetitively using hammers without error. What Woodworth observed and described, Fitts quantified through Fitts' law, generally known as the speed-accuracy tradeoff (Fitts, 1954). Fitts Law states that movement time increases as target width (W) decreases and the movement amplitude (A) increases (Fitts, 1954; Fitts & Peterson, 1964). An index of difficulty (ID) can be calculated for each rapid aiming movement based on the equation: $ID=\log_2 (2A/W)$ (Fitts, 1954; Fitts & Peterson, 1964). Increasing ID results in a longer movement time (MT) (Fitts, 1954; Fitts & Peterson, 1964).

Numerous researchers have investigated if Fitts' Law holds true for a variety of rapid aiming movements. Movements of all types have been explored and results indicate that Fitts' Law describes them all, thus establishing that it is a robust principle (Abrams & Pratt, 1993; Crossman & Goodeve, 1963, 1983; Drury, 1975; Jagacinski, 1989 Langolf, Chaffin, & Foulke, 1976; Meyer et al., 1988).

The next question, then, is why is Fitts' Law true? Woodworth divided the aiming movement into two phases: initial adjustment and current control (1899, as cited by Meyer et al., 1990). Research since then has supported this observation and incorporated these phases into the explanation. One explanation for Fitts' Law is that the limb is propelled half the distance to the target in the initial phase and half again in the second phase; the distance is divided again in half by an additional phase and these multiple iterations continue until the limb reaches its target (Crossman & Goodeve, 1963, 1983). However, this iterative model is no longer accepted as the best explanation.

A current explanation for Fitts' Law is found in the optimized submovement model (OSM), proposed by Meyer and his colleagues (Meyer et al., 1988). In this model the two (or more) submovements are optimized in order to minimize overall movement time (MT). The primary submovement (T1) is the ballistic phase and is used to travel much of the distance to the general target area. The primary submovement is the preprogrammed aspect of the movement with the end of T1 occurring when the acceleration curve crosses the zero or baseline from negative to positive after maximum deceleration (Ketcham, Seidler, Van Gemmert, & Stelmach, 2002; Yan, Thomas, Stelmach, & Thomas, 2000; Yan, Thomas, & Payne, 2002). During T2, the secondary submovement, online information is used to "home in" on and contact the target. Because T2 requires spatial precision, the online control inherent in T2 is more time consuming than is the preprogrammed control of T1.

The OSM states that the first submovement is optimized in order to minimize overall MT. If the first submovement is too fast, then the spatial variability in the end point of the first submovement is greater, thus creating a longer T2 and increasing the overall MT. In contrast, if T1 is executed more slowly, thus reducing its variability, the overall time greatly increases. Therefore, the goal is to optimize the speed and variability of T1, thereby minimizing overall MT. The OSM has gained support from numerous studies throughout the investigation of rapid aiming movements (Abrams & Pratt, 1993; Belgrove, Phillips, Bradshaw, & Gallucci, 1998; Khan & Franks, 2000, 2003; Meyer et al., 1990; Pratt, Chasteen, & Abrams, 1994; Thomas, Yan, & Stelmach, 2000).

By studying the kinematics and submovements of rapid aiming, underlying processes can be examined and by providing practice and observing retention, the changeability of these processes can be examined in differing populations. Studying young adults, older adults, and Parkinson's patients will provide insight into the effects of aging and Parkinson's disease during rapid aiming. Additionally, few studies have investigated practicing the rapid aiming movement for longer than one week. Long-term distributed practice of rapid aiming has not been explored. Additionally, few studies have explored long-term retention on any population.

The goals of this experiment are fourfold. The first goal is to investigate if the changes that occur during the practice of large and small rapid aiming in young adults are retained up to three weeks. The second goal is to investigate if older adults, who are provided distributed practice across weeks, will exhibit increased preprogramming (i.e., increased percentage of total time in T1) of rapid aiming and use online feedback more efficiently (i.e., decreased zero acceleration crossings). A third goal is to explore if people with PD perform large and small rapid aiming similarly to age-match controls after distributed practice, or if the disruption of Parkinson's is in addition to aging. The fourth goal is to assess if improvements are retained in older adults and Parkinson's patients.

## LITERATURE REVIEW

Woodworth first studied rapid aiming, making note of a speed-accuracy trade-off and observing that there was one portion of an aiming movement that was ballistic and one part that was more vision-driven (Meyer et al., 1988; Woodworth, 1899). Fitts (1954) formalized the speed-accuracy trade-off with the Index of Difficulty (Fitts, 1954; Fitts & Peterson, 1964), and a variety of studies in which the type of aiming task has been manipulated have shown that this law is robust. Attempts to understand and explain this law have built on Woodworth's original observation of two parts to the aiming movement (Crossman and Goodeve, 1963, 1983; Schmidt, Zelaznik, Hawkins, Frank & Quinn, 1979). In fact, it has been shown that both the ballistic portion of the movement (T1) as well as the error-corrective portion of the movement (T2) both abide by Fitts Law (Fitts, 1954; Fitts & Peterson, 1964). The most recent theory that helps to explain how both parts (or submovements) are organized into a coordinated aiming movement is the optimized submovement model (OSM), in which the speed of T1 is optimized to be as fast as possible, yet minimizing variability, thereby minimizing time spent in T2 (Meyer et al., 1988).

The vast majority of research investigating rapid aiming lending its support to the OSM has been conducted on young adults (Abrams & Pratt, 1993; Pratt et al., 1994; Pratt & Abrams, 1996; Khan & Franks, 2000, 2003). Initially, the overall rapid aiming movement of young adults consists of approximately 70% of the distance covered in T1 (Pratt et al., 1994). However, the time it takes the novice to complete each submovement is approximately the same (Abrams & Pratt, 1993; Pratt et al., 1994).

With practice young adults change the percentage of time in T1 and T2 (Abrams & Pratt, 1993; Pratt & Abrams, 1996). They increase their T1 time by improving the preprogramming aspect of the movement, thus making a more accurate movement with more speed (Abrams & Pratt, 1993; Khan & Franks, 2000; 2003). This improvement leads to an increase in the distance covered in the T1 with practice (Abrams & Pratt, 1993; Pratt et al., 1994). Optimizing T1 leads to a faster execution of the overall movement. With practice, the improvement enables young adults to have a faster MT and also a faster reaction time (RT) (Goggin & Meeuwsen, 1992; Yan et al., 2000; Yan et al., 2002). Thus, young adults travel farther in less time with rapid aiming practice (Abrams & Pratt, 1993).

In addition to becoming more accurate in programming the movement, young adults also become more efficient in utilizing feedback during T2 with practice, decreasing the need for multiple secondary submovements (Pratt et al., 1994). They also decrease the time spent in the T2 phase with practice (Abrams & Pratt, 1993). Young adults improve their aiming by decreasing their time to peak velocity and reducing their deceleration phase (Ketcham et al., 2002). With practice young adults tend to decrease their end-point variability (Pratt & Abrams, 1996). Practice effects can be seen in young adults in as little as a few dozen practice trials (Pratt et al., 1994). Similar movement changes were observed in studies with minimal practice and studies with extensive practice (Abrams & Pratt, 1994; Khan & Franks, 2000, 2003).

Multiple investigators have explored changes in the rapid aiming movement, which occur with practice (Abrams & Pratt, 1993; Khan & Franks, 2000, 2003; Pratt & Abrams, 1996; Pratt et al., 1994; Thomas et al., 2000; Yan et al., 2000; Yan et al., 2002). Khan and Franks (2000, 2003) and Chaput and Proteau (1996) measured same day transfer task. However, few studies have explored if these improvements in the aiming movement attained via practice are *retained* in young adults.

It has been well documented that the aiming movements of older adults are significantly different from that of young adults (Goggin, & Meeuwsen, 1992; Ketcham & Stelmach, 2001, Pratt et al., 1994; Teeken et al., 1996; Walker, Philbin, & Fisk, 1997; Yan et al., 2002; Yan et al., 2000). One global difference is that the duration of their rapid aiming movements are longer than young adults (Chaput & Proteau, 1996; Ketcham & Stelmach, 2001; Pratt et al., 1994; Teeken et al., 1996). Teeken et al. (1996) reported that older adults' average MTs are 150 ms longer than that of young adults during a discrete aiming task. Gogging and Meeuwsen (1992) observed a 62% increase in MT for older adults when compared to young adults during a rapid aiming movement. A number of factors may contribute to this slower movement. Walker et al. (1997) proposed four factors for how aging changes movement and these factors can be applied directly to explaining longer rapid aiming movements.

First, as seen in their own experiment, Walker et al. (1997) observed a great desire for *accuracy* of movement in older adults. Secondly, older adults have *less efficient processing of feedback* resulting in a less efficient closed-loop control (i.e., slower online processing) for movement. Third, there is an *increase of noise-to-force ratio* in older adults. Noise is an error, which occurs when the signal is mistakenly transmitted to the muscle for movement. This unintentional noise increases variability in movements, including rapid aiming movements. And last, older adults have a *decreased ability to produce force* in their movement. It is more difficult for older adults to produce the same muscular contraction than young adults. Each of these four factors has specific implications for changes with aging in discrete rapid aiming.

As aforementioned, older adults place a high value on the *accuracy* of their movements (Bellgrove et al., 1998; Chaput & Proteau, 1996; Walker et al., 1997). Walker et al. (1997) assigned differing penalties to certain trials of rapid aiming. Young adults had a greater T1 percentage of time when the penalty score was low than when it was higher. However, older adults contributed the same T1 percentage when the penalty was low or high. This suggests that even when older adults were not penalized for missing, they still intrinsically treated movement accuracy as a high priority.

The second of Walker's (1997) factors, that older adults process *sensory information more slowly*, also impacts the speed of movement. Older adults control much of their rapid aiming movements online despite requirements of the movement (Goggin & Meeusen, 1992; Ketcham & Stelmach, 2001;Walker et al., 1997; Yan et al., 2002). In addition, unlike the MT patterns typical of young adults, older adults' MTs are differentially affected by increases in ID. The MT of older adults increased as a greater rate with increases in ID than that of young adults (Goggin & Meeuwsen, 1992; Ketcham et al., 2002).

Older adults also do not use the information available to preprogram the movement before they start their movement. The reasoning for this phenomenon may not be a result of preference, but of limited capacity for producing more precise movements. Bellgrove et al. (1998) observed that older adults had significantly poorer performances when the task required increased precision than young adults. The decreased ability to preplan movements leads to poorer movement programming and a greater reliance on visual feedback. Rabbitt (1982) theorized that older adults rely on reactive mechanisms when producing movement, whereas young adults are more predictive in their movements. The older adults' decreased sensorimotor system may also add to the dependence on other feedback mechanisms (Chaput

& Proteau, 1996). This reliance on visual feedback has also been attributed to central programming or neuropsychological deficiencies (Goggin & Meeuwsen, 1992).

Thus, deficiencies in central programming require more reliance on T2. Ketcham et al. (2002) reported that older adults make more "discrete submovements" to reach their target than young adults. Further, older adults made significantly more submovements to reach their target than younger counterparts (Ketcham et al., 2002; Pratt et al., 1994; Yan et al., 2002). In fact, older adults spend more time in T2 during their movement than in T1. This indicates that T1's primary purpose, to propel the limb to the general area of the target, is compromised in older adults, thus, requiring either more time in T2 or more secondary submovements to compensate for lost distance (Bellgrove et al., 1998; Pratt et al., 1994; Ketcham et al., 2002; Yan et al., 2000).

The above results can be explained using Walker's (1997) last two factors mentioned above, *increased noise to force signal ratio* and an *inability to consistently produce force*. If preprogramming the ballistic portion of the movement (T1) cannot consistently and accurately be accomplished, then this portion of the discrete aiming task will be de-emphasized and T2, the online control, will be relied upon more.

In support of difficulties consistently programming force, time to peak velocity and peak velocity are also different in older adults (Goggin & Stelmach, 1990; Goggin & Meeuwsen, 1992; Ketcham et al., 2002). They typically have a longer time to peak velocity and decreased peak velocity than young adults (Ketcham et al., 2002) and are more variable when producing forces at higher maximum levels than young adults (Goggin & Stelmach, 1990).

Another characteristic of rapid aiming in older adults is a lack of smoothness, as measured by jerk (Yan et al., 2000). Jerk is the change in position over the change in acceleration of the movement, thus is a measurement of smoothness (Yan et al., 2000). Yan et al. (2000) suggested that because older adults spend less time preprogramming the movement (consider less MT in T1) there is an increased need for online feedback. Online feedback creates a slower T2 and results in a greater normalized jerk. They found that with practice older adults are able to improve central control and decrease the reliance on online feedback. Yan and his colleagues (2000) state that increases in the variability of force production also increase normalized jerk.

The ability of older adults to improve their rapid aiming with practice is unclear. Pratt et al. (1994) tested their participants' ability to rapid aim with forearm rotation. Researchers observed no shift in the older adults' submovements with practice. The same finding was observed in Seidler-Dobrin and Stelmach (1998). Chaput and Proteau (1996) found that even with practice older adults process visual information more slowly. Yan et al. (2000) observed that older adults were able to improve their discrete aim by decreasing MT, and increasing the distance traveled in the first submovement. The older adults' movement has been characterized by a preference for multiple T2 to reach the target (Yan et al., 2000).

However, few experiments have addressed the effects of distributed practice completed over weeks on movement changes in older adults. Pratt et al. (1994) incorporated 100 trials of practice in their first experiment and 200 trials in their second. Seidler-Dobrin and Stelmach (1998) included 180 trials of practice and Chaput and Proteau (1996) had participants practice 200 discrete aiming trials. Thus, it is unclear if distributed practice over weeks would shift either the underlying control of discrete aiming, such as an increased reliance on T1, and/or cause more efficient processing of information. Futhermore, the degree to which changes are retained with distributed practice is also unclear.

Parkinson's disease is the result of dopamine loss in healthy individuals and reduced dopamine is responsible for the bradykinetic effects in Parkinson's disease (Reeves, Bench, & Howard, 2002). The slowness in executing movements typical in Parkinson's disease is defined as bradykinesia (Majsak, Kaminski, Gentile, & Flanagan, 1998; Platz, Brown, & Marsden, 1998; Sheridan & Flowers, 1990; Smiley-Oyen, Worringham, & Cross, 2002;). Interestingly, every decade humans lose 3-7% of their endogenous dopamine in their substantia nigra (Reeves et al., 2002). Therefore, at age 70 the average healthy individual has lost approximately 35% of the dopamine levels found in young adults. For PD symptoms to become apparent, people must lose 70-80% of young adult dopamine levels (Schultz & Romo, 1992). Thus, the study of PD has been viewed by some as an extension of the effect of aging on human movement. Could some of the movement deficiencies seen in older adults be the result of decreased dopamine? This can be studied by comparing the rapid aiming movements of young adults and older adults to those of Parkinson's patients.

There are relatively few studies investigating discrete rapid aiming in Parkinson's patients. However, it is generally accepted that the overall aiming movements of patients are slower, more variable in speed, and have less accuracy than their neurologically healthy counterparts (Behrman et al., 2000; Platz et al., 1998; Romero, Van Gemmert, Adler, Bekkering, & Stelmach, 2003; Sheridan & Flowers, 1990; Worringham & Stelmach, 1990; Stelmach & Worringham, 1988). Researchers also agree that this movement degradation is due, at least in part, to the effects of bradykinesia (Majsak et al., 1998; Platz et al., 1998; Sheridan & Flowers, 1990; Smiley-Oyen et al., 2002; Stelmach & Worringham, 1988;).

Studies observe Parkinson's patients to have slower MTs and spent more time in T1 than age-match controls in discrete rapid aiming movements (Romero et al., 2003; Stelmach & Worringham, 1988; Worringham & Stelmach, 1990). However, a study by Behrman et al. (2000) found that patients showed no significant differences in RT and MT in discrete aiming movements when compared to age-match controls. Little information is provided in literature on the movement characteristics of T2 in PD.

Information on the movement kinematics of Parkinson's patients seems to coincide with their other movement characteristics. When executing a rapid aiming movement, patients have decreased acceleration and have more variability in their speed throughout the movement when compared to age-match controls (Romero et al., 2003; Sheridan & Flowers, 1990).

Smiley-Oyen, et al. (2002) studied sequential rapid aiming in Parkinson's patients. They found Parkinson's patients compared to age-matched controls to have slower RTs and MTs; they also showed decreased peak velocity and acceleration in sequential aiming tasks. However, with practice Parkinson's patients improved their RT, MT, peak acceleration, and velocity (Smiley-Oyen et al., 2002). Parkinson's patients were able to improve their rapid aiming movements with practice, but to a less degree than healthy age-matched controls (Stelmach & Worringham, 1998, 1990; Smiley-Oyen et al., 2002; Majsak et al., 1998).

Researchers have theorized about the mechanisms utilized by Parkinson's patients to compensate for their degraded movement. Sheridan and Flowers (1990) suggested that the increased end point variability observed in Parkinson's patients could be reduced by completing slower movements with smaller amplitudes. This technique, shuffling, is used on a larger movement scale to enable patients to walk securely (Sheridan & Flowers, 1990).

Romero et al. (2003) concluded that Parkinson's patients utilize their visual information to a greater extent than age-match controls. This technique acts to compensate for the insufficiencies of other feedback systems required for normal movement.

Again, only a few studies have investigated the Parkinsonian rapid aiming movement, but even fewer studies have explored PD as it relates to practice of the rapid aiming movement. Behrman et al. (2000) studied a simple and complex aiming movement with practice. Patients practiced both movements for 120 trials. Ten-minute and a 48-hour retention tests were assessed. Researchers found a decrease in RT and motor time after practice of the simple aiming movement. When baseline measures were compared to immediate and delayed retention measures, patients' performances did not return to baseline levels. Behrman et al. (2000) concluded that patients were able to retain their improvement of this task.

Another group (Platz et al., 1998) investigated rapid aiming practice with patients. Parkinson's patients practiced a 20 cm movement over 115 trials. An immediate retention test, 15 minutes after practice, was conducted. Platz et al. (1998) found that MT decreased with practice. Further, patients improved their MT by increasing the time spent in T1, as seen in young adults. Patients were able to retain their improvement to the immediate retention test. Platz et al. (1998) also saw the effects in the patients' movements were decreased after practice of the movement. Other studies support the notion that practice reduces bradykinetic effects (Majsak et al., 1998; Smiley-Oyen et al., 2002).

It is unclear if Parkinson's patients are able to improve their rapid aiming movement to the level of age-match controls, or if the reduced dopamine in patients creates a compromised ability to improve. In addition, more research is needed regarding how patients learn movements and their ability to retain this movement after distributed practice.

It is hypothesized that young adults will improve discrete rapid aiming by decreasing MT, increasing percent time in T1, increasing peak velocity and decreasing time to peak velocity with practice. It is also hypothesized that these changes will be retained. Healthy young adults do not have defects in their dopamine system; therefore, it is also expected that young adults will improve and retain movement improvements.

Secondly, it is hypothesized that older adults will improve discrete rapid aiming with distributed practice as evidenced by a faster MT and a higher peak velocity, but that their absolute values will not equal that of young adults (Behrman et al., 2000; Platz et al., 1998). In addition, it is hypothesized that with distributed practice older adults will rely more on preprogramming as evidenced by a greater percentage of time in T1. Furthermore, older adults are expected to retain their movement improvements.

Thirdly, it is hypothesized that people with PD will improve their rapid aiming performance with practice (shorter MT) despite their compromised dopamine system. More specifically, it is expected that people with PD will exhibit greater improvement in the small target condition than in the large target condition. However, regardless of condition, it is expected that their absolute performance even after practice will not be equal to their age-matched control group. It is also hypothesized that even with distributed practice the PD group will not rely more on preprogramming. Moreover, it is hypothesized that all improvements attained with practice will not be retained to the same degree as age-matched controls.

# METHODS

## Participants

Seven people with PD (66.3 yrs, ± 6.4), seven age-matched healthy older adults (OA) (66.4, ± 4.5), and seven healthy young adults (YA) (22.5, ± 1.2) participated in this study. Medical doctors clinically diagnosed Parkinson's patients; medical evaluations were compiled for patients. All patients possessed minimal to moderate symptoms of bradykinesia and tremor, and no signs of cognitive impairment (see Table 1 for patient description) Patients were tested while on medication. Participants were recruited in agreement with institutional standards. Before the experiment began, all participants signed informed consent forms. All participants who began the experiment completed it. The PD and OA were given $500 for their involvement in the study. The YA were given either $100 or class credit. (The YA engaged in only part of the overall study that involved multiple tasks.)

Participants completed numerous tests to establish cognitive and motor abilities. Tests completed were: the Beck Depression Inventory (Beck & Steer, 1987), the Mini Mental State Examination (MMSE), the Symbol Digit Modalities Test (Smith, 1982), the Shipley Institute of Living Scale, the Hand Dominance survey, the Purdue Pegboard (Lafayette Instruments), Reciprocal tapping, and the Bassin Timer (Lafayette Instruments). Ages, birth date, gender, and years of education were obtained from participants. The MMSE, Symbol Digit Modalities Test, Shipley Institute of Living Scale, and Hand Dominance survey were only collected once during the initial meeting. Participants completed the Beck Depression Inventory every two weeks of the experiment. The Purdue Pegboard, Reciprocal tapping, and Bassin timer were conducted during each laboratory testing session. The results of the above tests were analyzed by an independent sample t-test (see Tables 2 and 3 for means and standard deviations).

Table 1 – Characteristics of PD group

| ID | Age (yrs) | Disease Duration (yrs) | Medications | Hoehn & Yahr Stage | Limb Brady-kinesia | Limb Resting Tremor | Limb Rigidity | Other Comments |
|---|---|---|---|---|---|---|---|---|
| 1 | 67 | 2.5 | Pramipexole Selegiline | II | minimal | none | minimal | bilateral involvement |
| 2 | 60 | 2 | Ropinirole | I | mild | none | mild | unilateral involvement |
| 3 | 62 | 1 | None | I | mild | mild | none | unilateral involvement |
| 4 | 74 | 10 | Carbidopa/ Levodopa Ropinirole Venlafaxine Clonazepam | II | moderate | mild | moderate | mild dyskinesia; bilateral involvement; moderate on/off fluctuations |
| 5 | 66 | 17 | Carbidopa/ Levodopa Pramipexole Amantadine | II | mild | none | none | moderate dyskinesia; bilateral involvement |
| 6 | 59 | 2.5 | Carbidopa/ Levodopa | I | mild | none | mild | unilateral involvement |
| 7 | 75 | 4 | Carbidopa/ Levodopa Mirtazapine | II | mild | mild | mild | bilateral involvement mild depression |

Table 2. Means and standard deviations of Cognitive and Motor Tests for OA and YA.

| Test | OA Group | YA Group |
|---|---|---|
| Education (years) | 16.1 (3.3) | 16.1 (1.4) |
| Beck Depression Scale (mild to moderate: 10-18) | 5.86 (6.2) | 4.4 (4.1) |
| Mini-Mental (30 = perfect score) | 30 (0.0) | 29.6 (0.8) |
| Symbol Digit (# of correct) | 53.0 (9.2) | 61.0 (13.9) |
| Purdue Pegboard (# of pegs) | 13.4 (1.4) | 15.7** (1.3) |
| Reciprocal Tapping (# of taps) | 36.1 (2.9) | 32.6 (7.1) |
| Bassin Timer (mean absolute error in ms) | 65.7 (27.0) | 48.2 (27.1) |

$^*p < 0.05$; $^{**}p < 0.01$

Table 3. Means and standard deviations of Cognitive and Motor Tests for PD and OA.

| Test | PD Group | OA Group |
|---|---|---|
| Education (years) | 15.9 (3.4) | 16.1 (3.3) |
| Beck Depression Scale (mild to moderate: 10-18) | 10.1 (8.8) | 5.86 (6.2) |
| Mini-Mental (30 = perfect score) | 29.9 (.4) | 30 (0.0) |
| Symbol Digit (# of correct) | 43.0 (13.0) | 53.0 (9.2) |
| Purdue Pegboard (# of pegs) | 11.0* (2.3) | 13.4 (1.4) |
| Reciprocal Tapping (# of taps) | 28.1** (5.1) | 36.1 (2.9) |
| Bassin Timer (mean absolute error in ms) | 74.4 (31.5) | 65.7 (27.0) |

$^*p < 0.05$; $^{**}p < 0.01$

## Task

Patients completed the rapid aiming movement with their most affected hand. Age-matched adults used the hand corresponding to a Parkinson's counterpart. Young adults all completed this experiment using their left hand, which was the non-dominant hand for all young adults; this was done so young adults would be challenged by the task enough to motivate them to effectively practice. The task consisted of starting with a hand-held stylus in on a home position and moving to the target as fast as possible while seated. Two target sizes were used in the experiment. The participants were instructed to complete the task as fast as they could while maintaining 90% accuracy.

## Apparatus

The centers of the targets were 35 cm from the starting position (a circular target 3 cm in diameter). The large target was 10 cm in diameter (ID = 3.2), while the small was 1.5 cm in diameter (ID = 6.8).

Six infrared light emitting diodes were used to collect x, y, and z coordinates of the movement. Two IRED diodes were placed on the posterior medial and lateral wrist just proximal to the radial and ulnar styloid processes. Two IRED diodes were placed on the posterior lateral and anterior midline of the humerus just proximal to the humeral epicondlyes. One IRED was placed approximately 1 cm proximal to the acromioclaviclar joint. The last IRED was placed 2.5 cm above the tip of the stylus held by the participants. The diodes were part of the OptoTrak Camera System (model 3020, Northern Digital, Ontario, 1 mm resolution). Data were collected at 200 Hz.

Procedures

The participants took part in an informational session at the start of the experiment. At this meeting the participants were informed of practice parameters, laboratory testing sessions, practice schedules, etc. Two weeks later the participants returned for their baseline (B) testing. After the initial testing, the participants started to practice the task for three weeks. One week after B, the participants completed their first performance (P1) session in the laboratory. For the next two weeks, participants returned for performance two (P2) and performance three (P3). After P3 the participants ceased practicing the task. Two days after P3, participants were tested on their first retention (R1). Then for the next three weeks from P3, participants were tested each week for retention two (R2), retention three (R3), and retention four (R4). The time lapse from B to R4 was seven weeks.

Practice Procedures. After instructed with practice procedures, all participants practiced for three weeks. Each Parkinson's patient and OA participant was given a replica of the testing apparatus to practice with at home. The YA practiced using a replica in a convenient location near the research lab on campus. The participants were instructed to complete eight practice sessions each week. Practice sessions followed a specific semi-blocked schedule, which consisted of six sets of five trials of both large and small target. Thus, the participants completed 240 trials for each target each week for a total of 720 trials completed during three weeks of practice at home. Participants kept practice journals in which they were instructed to record the time of the final trial for each 5-trial set and the number of spatial errors they made in that set. To promote experiment adherence and accurate performance participants were visited during a practice session once a week by the researcher. After completing three weeks of practice, participants stopped practicing and retention testing began.

Testing Procedures. Participants were tested in the Iowa State Motor Control Laboratory a total of nine times. During laboratory testing sessions, participants were given knowledge of results (KR) and knowledge of performance (KP) only for the three weeks they practiced at home. During the retention assessments, KR and KP were not given to the participants.

An auditory warning tone followed by a 'go' tone (at random intervals varying between 800 and 1200 ms) signaled the start of the movement throughout testing sessions. Participants were told to complete the movement as fast as possible with accuracy. Participants were instructed to miss no more than one out of ten trials for 90% accuracy. At the completion of a trial the participant moved back to the start position and awaited the warning tone. During laboratory testing, participants completed twelve trials of each target. If the participants missed the target, they were instructed to do the trial again. If they missed more than one trial, participants were instructed to slow down as not to miss the target again. If they had not missed a single trial by trial ten they were informed to speed up slightly. Error trials or missed trials were repeated.

## Data Reduction and Analysis

The data were filtered with a $2^{nd}$-order Butterworth filter using a 21 Hz low pass cutoff frequency (Smith, 1989). For short duration movements a higher cutoff frequency is desirable since abrupt movements tend to consist of higher frequency components that are important for more accurate analysis. Thus, this cutoff frequency was selected to optimally remove noise without eliminating important signal information (Winter, 1990).

The onset of movement was defined as the first point in which there were 5 consecutive samples in which velocity increased. Velocity of movement was determined based on the absolute change in the OptoTrak position data from the wrist IRED. Movement time was from the onset of movement until contact with the target. Visual confirmation via 3-D playback was used to check for correct identification of the beginning and end of the movement.

Movement time was measured to provide an overall description of execution. Kinematic measurements of the first segment were examined to provide insight into offline and online control. These variables were: 1) time to peak velocity; 2) time after peak velocity; and 3) number of submovements, a submovement was defined as the acceleration curve crossing from low to high after peak deceleration, and a crossing had to be maintained for at least four consecutive samples (20 ms) to be counted as a real crossing. In addition, coefficient of variation (CV) of PV and TTPV for the first segment was examined to assess variability of the initial force impulse. The CV was used rather than standard deviation to account for mean differences in variables, thus controlling for inherently greater variability in higher means.

The primary dependent variables analyzed were MT, time to peak velocity, time after peak velocity, percentage of MT in first submovement, number of zero crossing of the acceleration curve, peak velocity, coefficient of variation of peak velocity, and coefficient of variation of time to peak velocity. Data were reduced by calculating a mean across trials for each participant. Trials in which the participants missed the target were not included in analyses (see Table 4 for a description of error rates for each group).

Table 4. Error Rates. Mean error rate by group and session.

| | B | P1 | P2 | P3 | R1 | R2 | R3 | R4 |
|---|---|---|---|---|---|---|---|---|
| **Large** | | | | | | | | |
| YA | 1.2% | 1.2% | 1.2% | 7.1% | 2.4% | 1.2% | 1.2% | 2.4% |
| OA | 2.4% | 0% | 2.4% | 0% | 1.2% | 0% | 1.2% | 0% |
| PD | 0% | 3.6% | 2.4% | 1.2% | 0% | 1.2% | 2.4% | 1.2% |
| **Small** | | | | | | | | |
| YA | 10.7% | 5.9% | 8.3% | 10.7% | 8.3% | 9.5% | 10.7% | 11.9% |
| OA | 14.2% | 8.3% | 10.7% | 9.5% | 7.1% | 9.5% | 10.7% | 10.7% |
| PD | 5.9% | 4.8% | 15.5% | 11.0% | 10.7% | 4.8% | 9.5% | 10.7% |

Separate analyses of variance (ANOVAs) were conducted to explore the effects of aging versus the effects of Parkinson's disease. Thus, OA and YA were analyzed in one ANOVA to investigate the effects of aging. PD and OA were analyzed in another ANOVA to investigate the effects Parkinson's disease. It should be noted that the OA group analyzed in both sets of analyses was the same group.

The descriptive statistics indicated that the data were not normally distributed. Skewness and kurtosis values were consistently above 1.0. To correct for this the data were ranked first before analysis and an L statistic was used to determine significance (Thomas & Nelson, 2001; Thomas, Nelson, & Thomas, 1999). The ranked data were analyzed using a group x session analysis of variance (ANOVA) with repeated measures on the second factor for the large target performance and a similar analysis for small target performance. Separate ANOVAs were conducted to examine changes with practice, learning, and retention. To measure changes with *practice* a Group (2) x Session (4: B1, P1, P2 and P3)

ANOVA with repeated measures on the last factor for each dependent variable was conducted. To measure changes in *learning* a Group (2) x Session (2:B, R1) ANOVA with repeated measures on the last factor for each dependent variable was conducted. To measure retention a Group (2) x Session (4: R1, R2, R3, R4) ANOVA with repeated measures on the last two factors was used to analyze each dependent variable. Statistical tests were set at a confidence level of .05.

# RESULTS

Throughout the presentation of the results OA and YA analyses will be stated first, then those for the PD and OA. For each dependent variable practice, learning, and retention will be addressed, respectively. All figures and tables include means and 95% confidence intervals (CI).

## Large Target

### Movement Time (MT)

Analyses of MT indicate if the participants increased and maintained the speed of the movement with three weeks of practice and, if so, how well they retained improvements across three weeks of retention see Figures 1 and 2 for MT means and 95% confidence intervals.

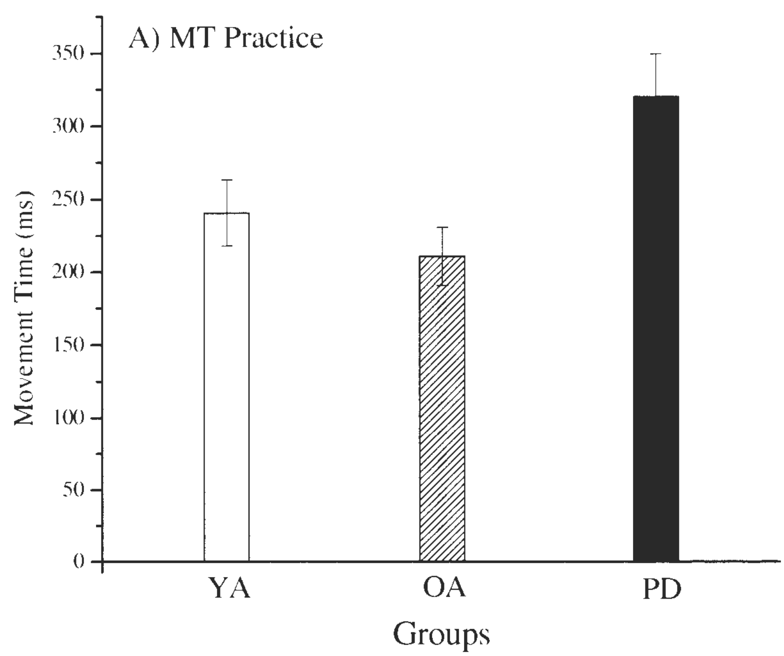
**OA and YA.** *Practice.* There was a group main effect, $L$ (1) = 7.93, .01 < p > .001, with the YA group exhibiting a faster MT than that of OA group. There was also a session main effect, $L$ (1) = 10.426, .05 < p > .02, indicating that both groups improved with practice, with both groups improving in a similar fashion. *Learning.* Again, there were both group and session main, Group: $L$ (1) = 8.08, .01 < p > .001, and session: $L$ (1) = 9.92, .01 < p > .001. *Retention.* Group was the only main effect in retention, $L$ (1) = 6.02, .01 < p > .001. There was no main effect for session, so both groups retained the increase in speed.

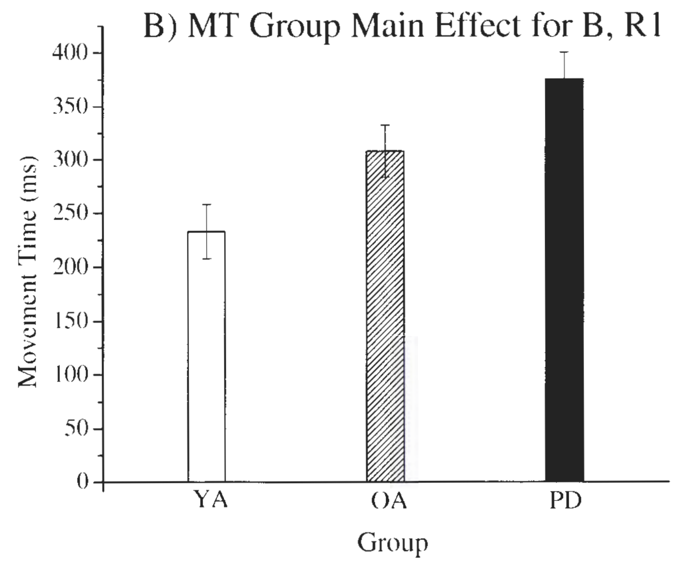
**PD and OA.** *Practice.* There were group and session main effects. The OA had significantly faster MT than that of PD, $L$ (1) = 8.49, .01 < p > .001. The session effect, $L$ (1) = 9.96, .05 < p > .02, indicated that both groups improved throughout practice. *Learning.* Again, there were both group and session main effects with the means in the same direction as in practice, group, $L$ (1) = 8.06, .01 < p > .001, and session, $L$ (1) = 8.32, .05 < p > .02.

*Retention.* Group was the only main effect in retention, $L$ (1) = 8.09, .01 < p > .001, indicating that both groups retained improvement and did so in a similar.

**Summary for MT.** The YA group was significantly faster than the OA group, and the OA group was significantly faster than the PD group, as expected. All three groups improved their mean speed with practice and maintained it across the three weeks of retention. No significant interactions indicate that the groups changed in a similar manner.

A) MT Group Main Effects for B – P3





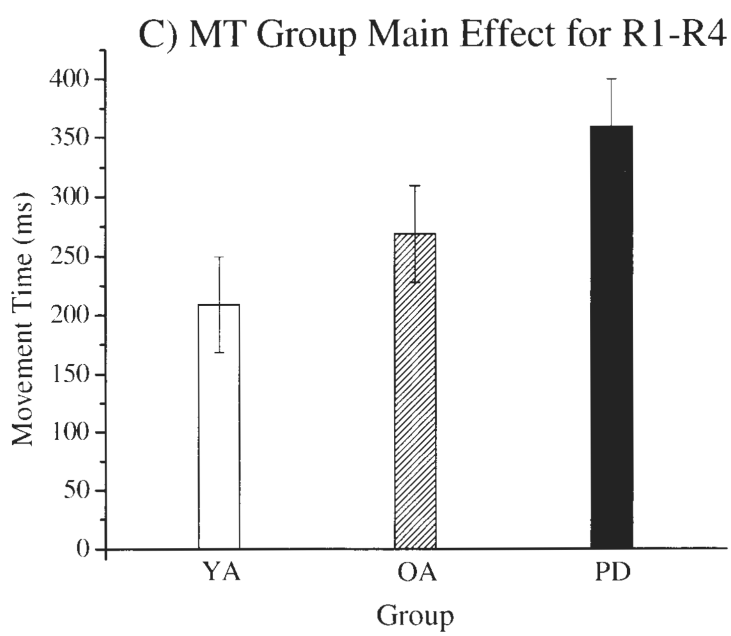
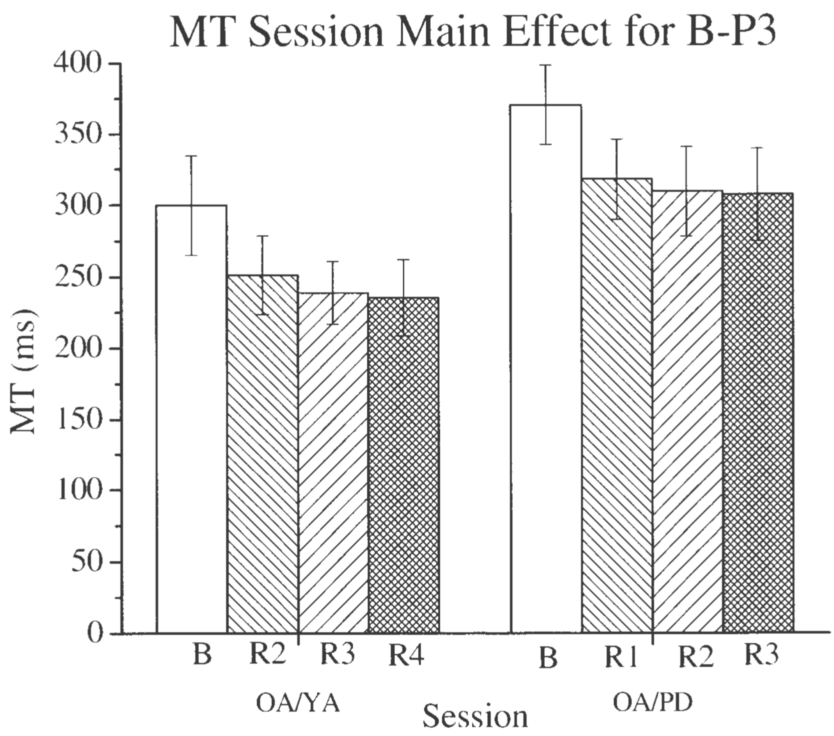




Figure 1 – Group main effects for MT large target



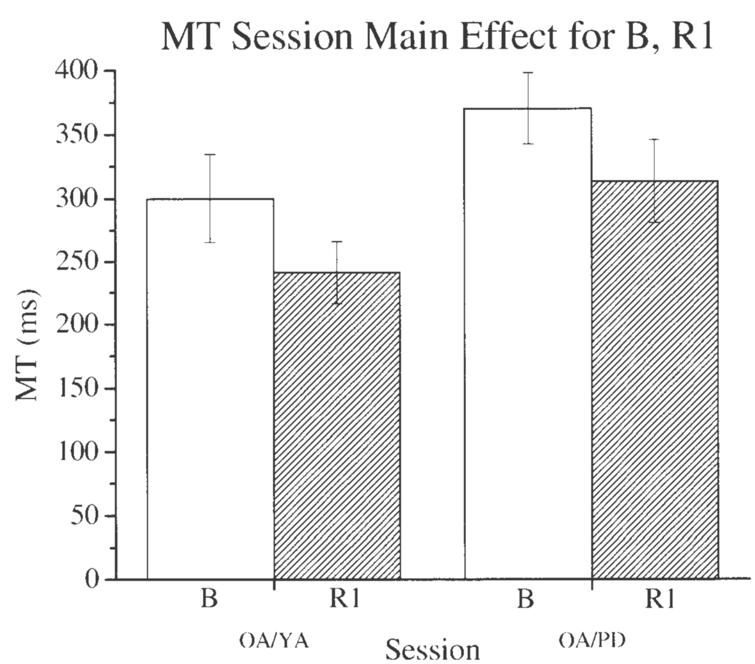




Figure 2 – Session main effects for MT large target

**Time to Peak Velocity (TTPV)**

Time to peak velocity has been proposed by some as the clearest measure during movement of preprogramming (Khan & Franks, 2003, 2000). Means and CI are presented in Figures 3 and 4.

**OA and YA.** *Practice.* There was a group main effect, $L$ (1) = 7.44, .01 < p > .001. The YA had a faster TTPV than the OA group. There was also a trend for a session effect, $L$ (1) = 8.75, .1 < p > .05. *Learning.* There was a group main effect, the YA maintained a faster TTPV in learning, $L$ (1) = 7.52, .01 < p > .001. There was also a session main effect; both groups decreased TTPV similarly, $L$ (1) = 8.91, .02 < p > .01. *Retention.* Again, there was a significant group main effect, $L$ (1) = 4.88, .02 < p > .01; the YA had a faster TTPV in retention than the OA group.

**PD and OA.** *Practice.* There was a significant session main effect, $L$ (1) = 10.96, .05 < p > .02, indicating that both groups improved similarly with practice. There was also a group trend, $L$ (1) = 3.79, .1 < p > .05. *Learning.* Group and session were both significant main effects. The OA maintained a faster TTPV, $L$ (1) = 4.49, .05 < p > .02. Both groups obtained faster scores with learning, $L$ (1) = 7.72, .05 < p > .02. *Retention.* There was a group trend, $L$ (1) = 3.26, .1 < p > .05; the OA were faster than the PD.

**Summary of TTPV.** The YA and OA improved their mean performance during learning. Both groups retained this improvement, as session was not significant during retention. However, the YA group was significantly faster than the OA during practice, learning, and retention, as expected. These group differences indicate that the YA are better able to preprogram their movement than the OA, but both groups can improve this aspect of the movement. Both the PD and OA groups were able to decrease their mean TTPV during practice and learning, which they also retained. The only significant group difference was observed during learning; the OA were faster than the PD. However, there were trends for both practice and retention group main effects, which suggest that the OA may be able to better preprogram their movement when compared to the PD group.

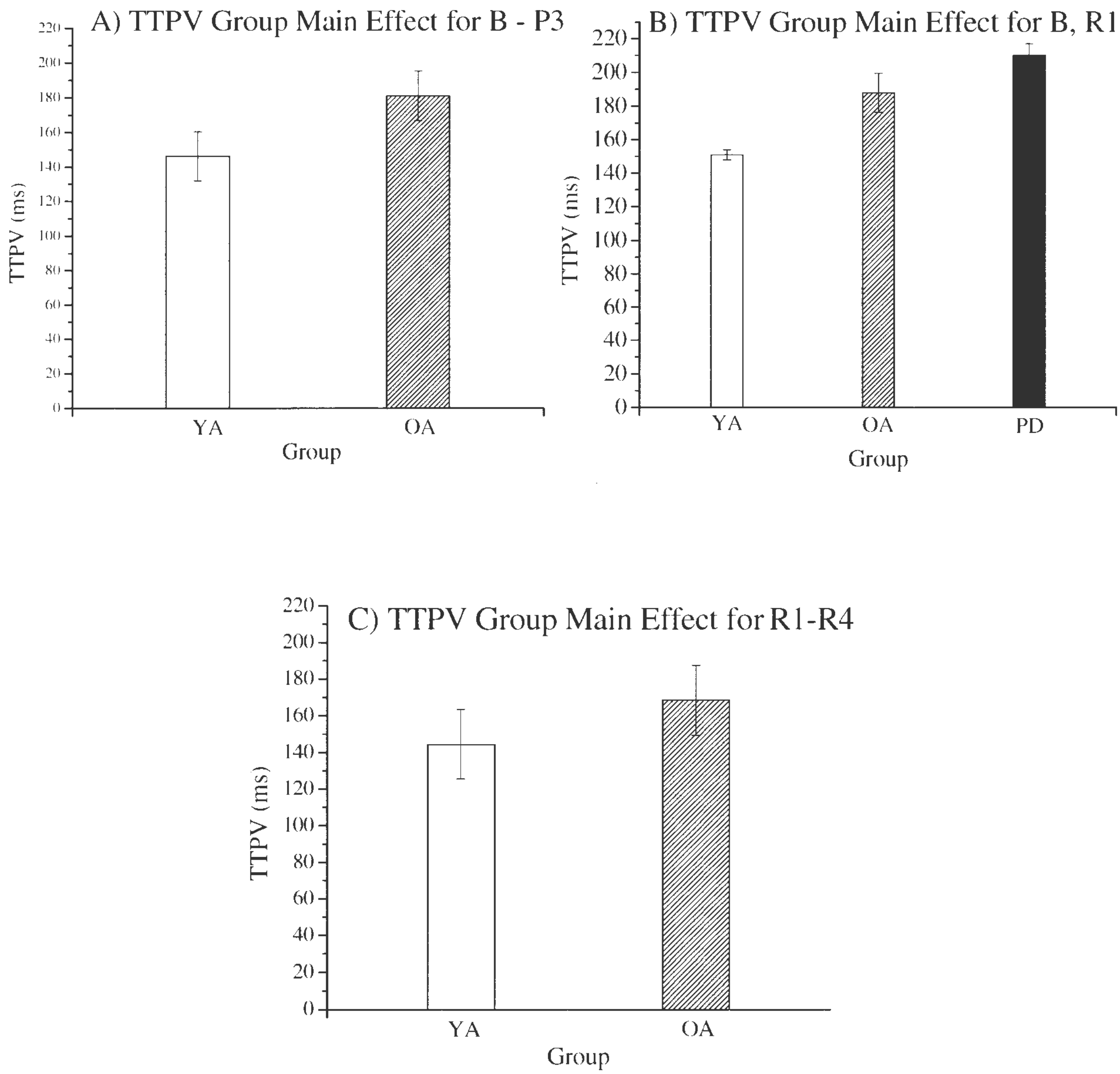



Figure 3 - Group main effects for TTPV large target

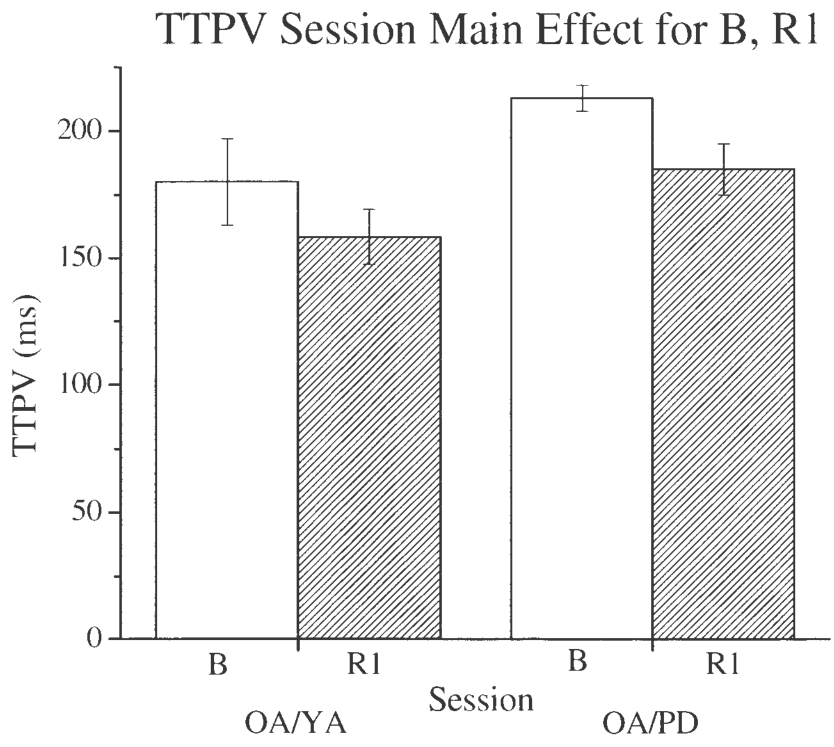



Figure 4 –Session main effects for TTPV large target

**Time After Peak Velocity (TAPV)**

Time after peak velocity is the segment of the movement that is influenced by online visual feedback (Khan & Franks, 2003, 2000). By examining TAPV, the efficiency of online feedback can be studied (see Figures 5 and 6 for means and CI of TAPV).

**OA and YA.** *Practice.* Group and session were both significant main effects of practice. The YA group had a significantly faster TAPV than the OA group, $L$ (1) = 6.72, .01 < p > .001. However, both groups significantly decreased TAPV, $L$ (1) = 11.90, .02 < p > .01. *Learning.* Again, group and session were both significant main effects. The YA group continued to have a faster TAPV than the OA group, $L$ (1) = 8.05, .01 < p > .001. Both groups improved TAPV, $L$ (1) = 8.68, .02 < p > .01. *Retention.* Group exhibited a significant main effect for retention; the YA maintained a faster TAPV compared to OA, *L* (1) = 6.13, .02 < p > .01.

**PD and OA.** *Practice.* Group was a significant main effect; the OA group had a significantly faster TAPV than the PD group, *L* (1) = 7.38, .01 < p > .001. There was also a session main effect. Each group significantly reduced TAPV, *L* (1) = 10.79, .02 < p > .01. There was also a group x session interaction trend, *L* (1) = 7.88, .1 < p > .05, implying that the groups reduced TAPV significantly different. *Learning.* Again, group and session were both significant main effects. While the OA group had a faster TAPV than the PD group, *L* (1) = 7.30, .01 < p > .001, each OA and PD group decreased TAPV, *L* (1) = 6.96, .05 < p > .02. *Retention.* Group was a significant main effect of retention. The OA maintained their faster TAPV compared to PD, *L* (1) = 6.08, .02 < p > .01.

**Summary of TAPV.** While the YA and OA significantly reduced mean TAPV during practice and learning, the YA were significantly faster in all measures than the OA. This group difference may be the result of more efficient use of online feedback by the YA. At each measure the OA exhibited faster mean TAPV than the PD. Similar to the OA and YA, the PD and OA reduced mean TAPV during practice and learning. All three groups maintained reduced mean TAPV in retention.

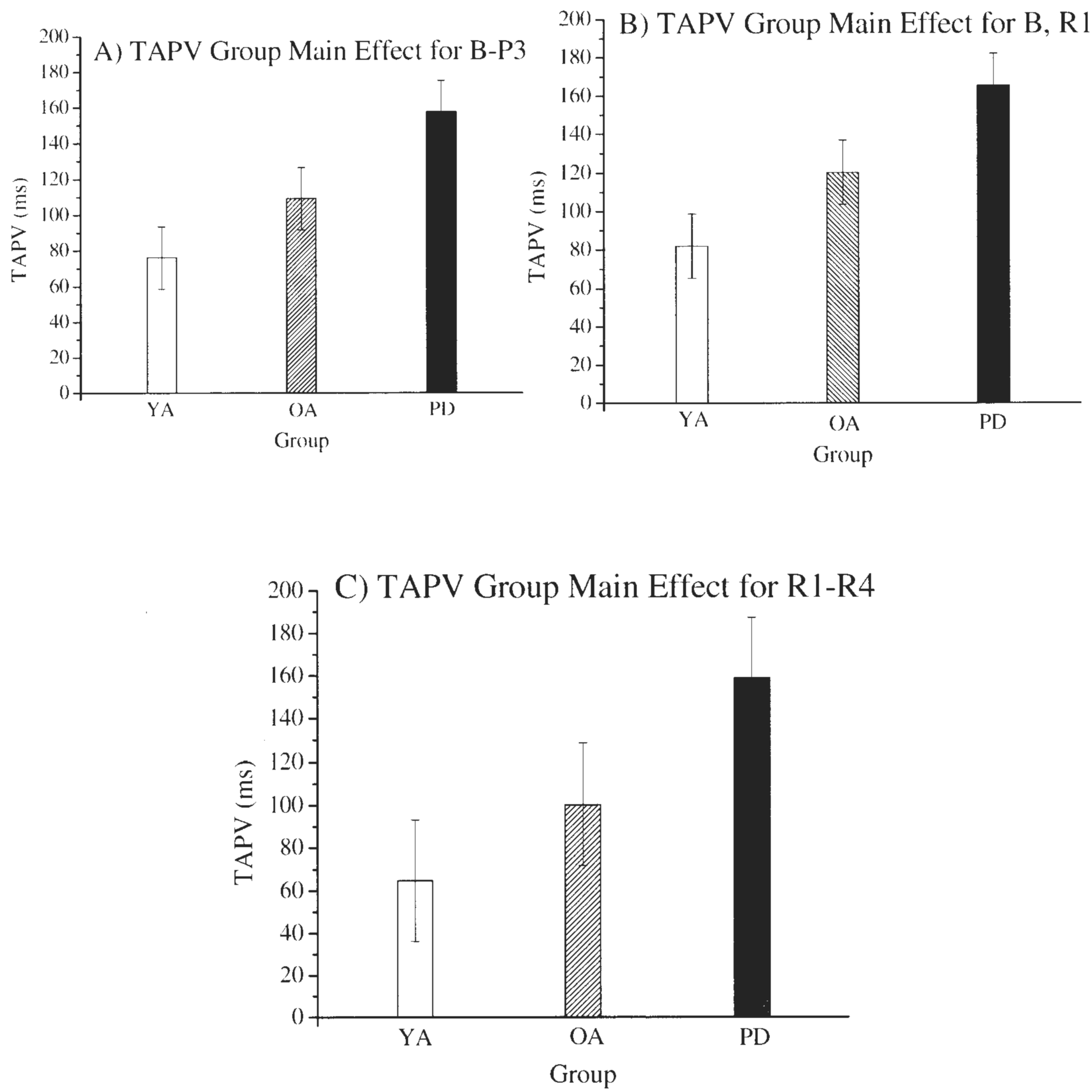
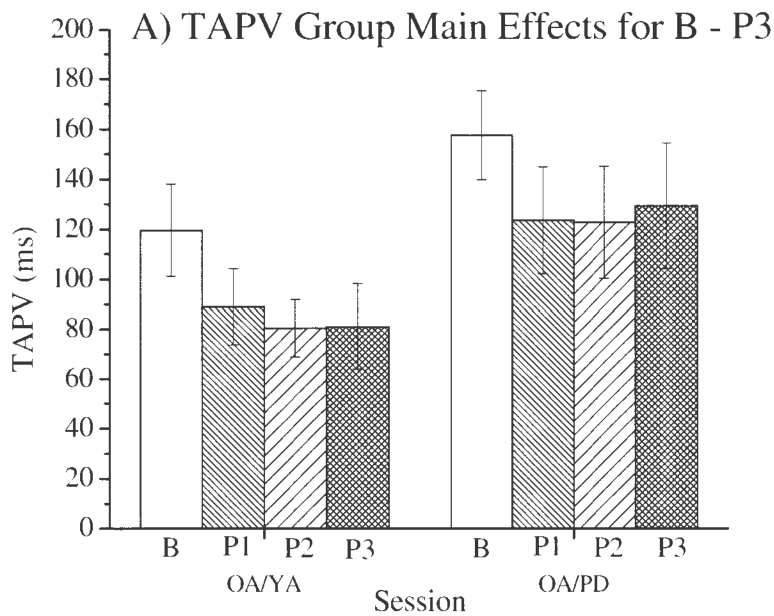



Figure 5 – Group main effects for TAPV large target



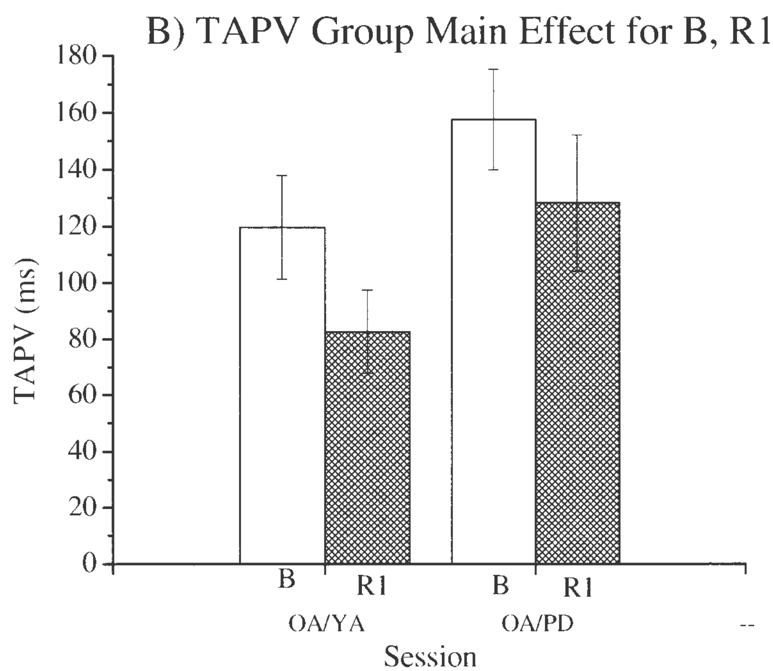




Figure 6 – Session main effects for TAPV large target

**Percent of Primary Submovement in Movement Time (%T1)**

The percentage of movement time spent in the primary submovement provides insight into the reliance on the preprogrammed or ballistic portion of the movement. It is also a traditional measure of rapid aiming (see Figures 7 and 8 for means and CI).

**OA and YA.** *Practice.* A significant main effect of practice was session. Groups significantly increased %T1 with practice, $L$ (1) = 11.36, .05 < p > .02. *Learning.* There was a session main effect in learning, $L$ (1) = 6.46, .05 < p > .02. However, instead of improving their performance they decreased %T1. *Retention.* There was a significant session main effect, $L$ (1) = 10.712, .05 < p > .02, both groups did not retain increased %T1 with practice.

**PD and OA.** *Practice.* Group was a significant main effect of practice, the OA had a significantly higher %T1 than the PD group, $L$ (1) = 4.31, .05 < p > .02. Session was also a main effect, groups increased %T1 with practice, $L$ (1) = 11.35, .05 < p > .02. *Learning.* Again, group and session were both significant main effects. The OA group continued to have significantly higher %T1 than the PD group, $L$ (1) = 4.08, .05 < p > .02. Similar to the OA and YA, instead of improving during learning, the PD and OA significantly decreased %T1, $L$ (1) = 6.85, .05 < p > .02. *Retention.* Group was a significant main effect, the OA group continued to demonstrate higher %T1 than the PD group, $L$ (1) = 6.28, .02 < p > .01. And, session was a significant main effect of retention; both groups continued to decrease %T1 in retention, $L$ (1) = 11.67, .02 < p > .01. There was also a group x session trend, $L$ (1) = 8.05, .1 < p > .05.

**Summary of %T1.** The YA and OA group improved mean %T1 during practice and learning. Further, there were no significant differences between the two groups' performances. The PD and OA also improved mean %T1 during practice and learning, but the OA had a higher mean %T1 than the PD throughout the experiment. However, none of the groups retained the greater mean %T1. Therefore, the inability to retain an improved mean %T1 appears to be the result of loss of practice and/or the lack of augmented feedback and not aging or disease. However, the PD group was significantly different from the OA group, which may point to the effects of Parkinson's disease. In other words, the PD group may not exhibit as high of scores due to their disease.

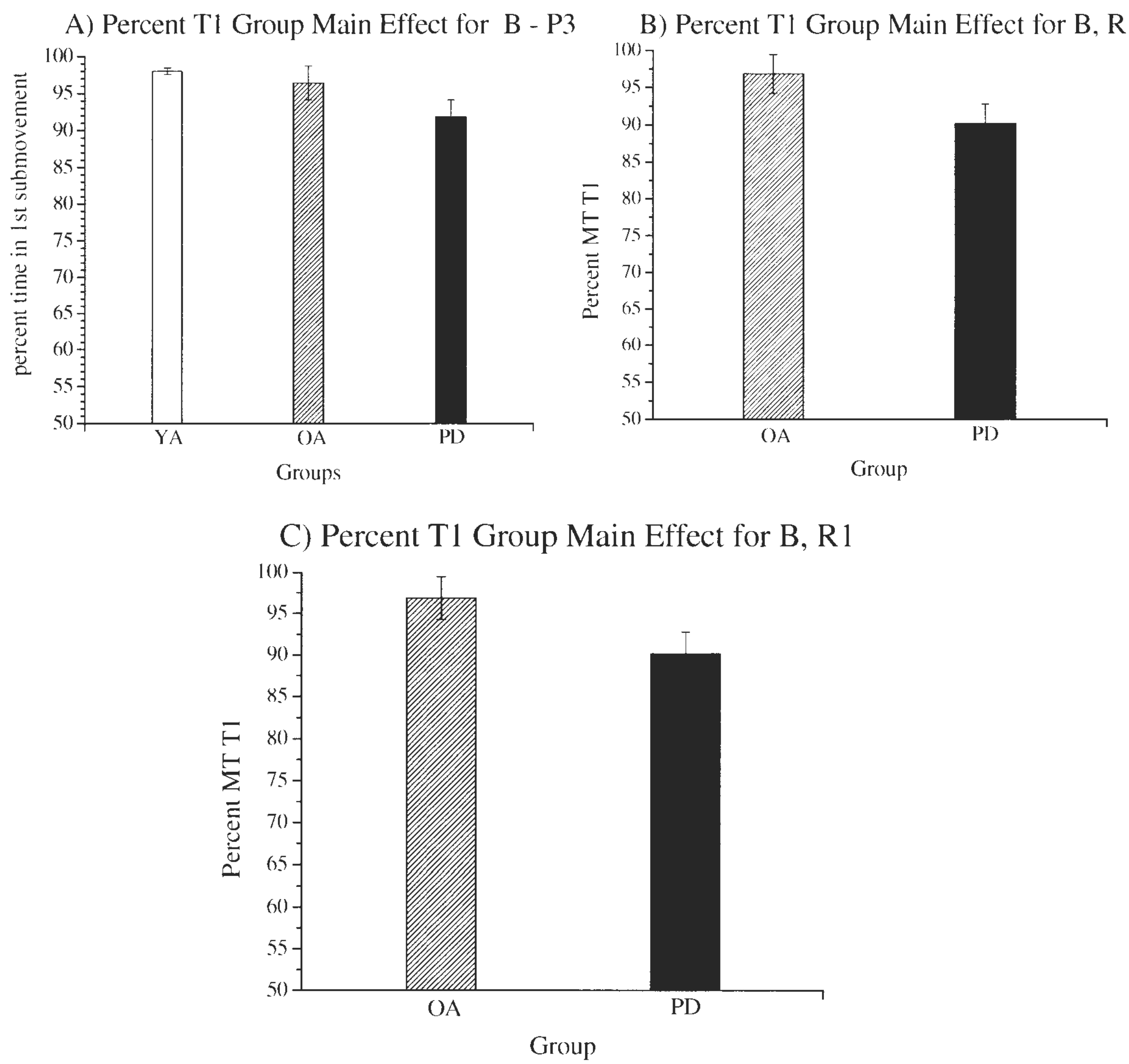
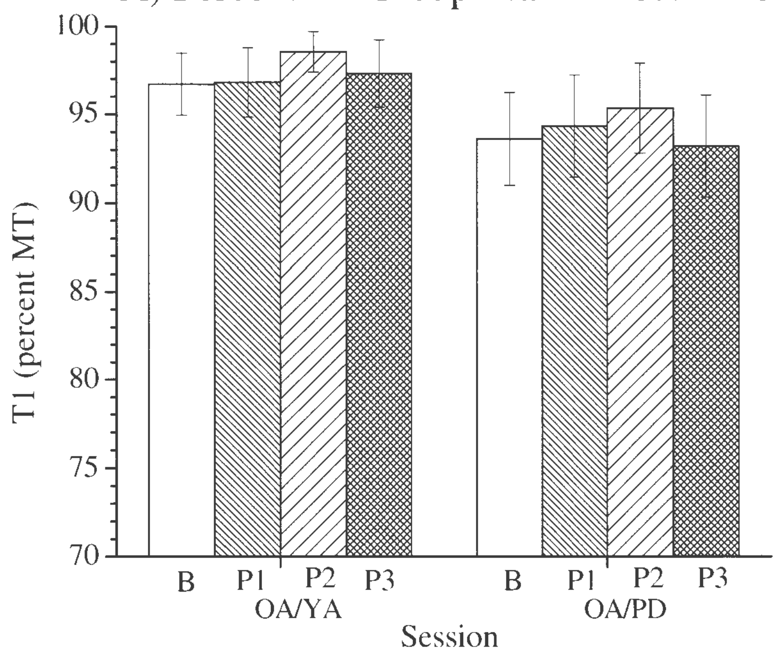
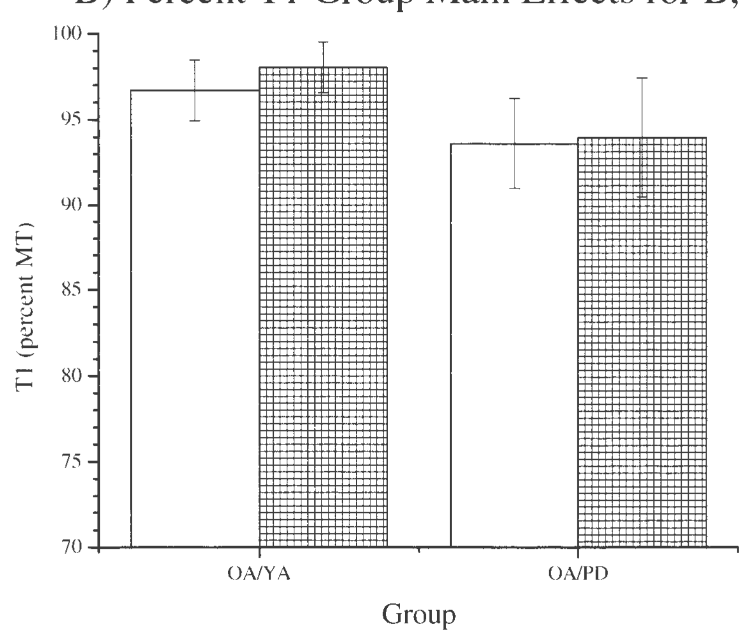



Figure 7 – Group main effects for %T1 large target

A) Percent T1 Group Main Effect B-P3




B) Percent T1 Group Main Effects for B, R1



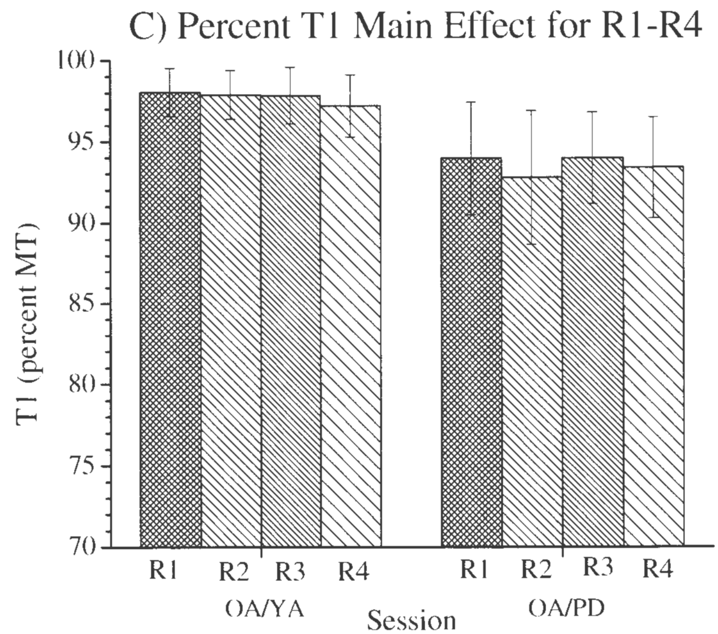



Figure 8 – Session main effects for %T1 large target

**Zero Acceleration Crossings**

Submovements were defined by the passing of the acceleration value over zero from a deceleration position, and is another measure of online control (van Donkelaar and Franks, 1991). The more acceleration crossings present in a movement the more secondary submovements (see Table 5 for means and CI).

**OA and YA.** *Practice.* There was a group trend, $L\ (1) = 2.79$, $.1 < p > .05$; the YA had fewer acceleration crossings than the OA. *Learning.* There were no significant differences. The groups were not significantly different in performance or improvement. Session $p > .2$ and group $p > .2$. *Retention.* Again, there were no significant differences in retention. Session $p > .5$ and group $p > .1$.

**PD and OA.** *Practice.* Group was a significant main effect, $L$ (1) = 6.09, .02 < p > .01. The PD group had more acceleration crossing than the OA group. *Learning.* There were no significant differences in learning. The groups were not significantly different in performance or improvement. *Retention.* There was a significant group main effect, the PD had significantly more acceleration crossings than the OA group, $L$ (1) = 6.11, .02 < p > .01.

**Summary of Zero Acceleration Crossings.** There does not appear to be any difference in the performance or improvement between the YA and OA groups. This indicates that the OA are able to execute the movement with the same number of zero acceleration crossings as the YA. Similar to the YA and OA, the PD and OA did not improve during practice or learning. There were group main effects during practice and retention for the PD and OA. These group effects may suggest that more zero acceleration crossings is the result of Parkinson's disease and not general aging, as the OA were not significantly different when compared to the YA group.

Table 5 - Group main effects for zero acceleration crossings large target

| Zero Crossings | Practice | Retention |
|---|---|---|
| OA | .31<br>(.05) | .28<br>(.02) |
| PD | .69<br>(.02) | .79<br>(.03) |

**Peak Velocity (PV)**

Changes in PV provide insight into the change in the initial preprogrammed force impulse. Means and CI are presented in Tables 6 and 7.

**OA and YA.** *Practice.* There was a group main effect, $L$ (1) = 10.04, .01 < p > .001. The YA exhibited a higher PV than the OA group. *Learning.* There was a group main effect.

Again, the YA demonstrated a higher PV than the OA group, *L* (1) = 8.74, .01 < p > .001. There was also a session main effect; both groups increased PV, *L* (1) = 9.37, .01 < p > .001. *Retention.* There was a group was a main effect, with the YA group maintaining a higher PV, *L* (1) = 9.30, .01 < p > .001.

**PD and OA.** *Practice.* There was a group main effect in practice, *L* (1) = 4.74, .05 < p > .02. The OA group had a higher PV than the PD group. *Learning.* There was a group main effect in learning, *L* (1) = 6.16, .02 < p > .01. The OA group maintained a higher PV. *Retention.* There was a trend for a group main effect, *L* (1) = 3.48, .1 < p > .05.

**Summary for PV.** The YA group exhibited a higher mean PV across practice, learning, and retention compared to the OA group, and the OA group exhibited a higher mean PV across practice and learning compared to the PD group. The average scores of the YA and OA group improved their PV during learning and retained their improvement. No significant changes took place with practice or learning in the average of the OA and PD group. After identifying contrasting conclusions observed in the OA group, a ranked repeated measures ANOVA was conducted during learning on only the OA group. There was no significant session main effect for the OA in PV, thus, the OA did not improve PV.

Table 6 - Group main effects for PV large target

| PV | Practice | Learning | Retention |
|---|---|---|---|
| YA | 313.80 (27.11) | 284.64 (31.67) | 306.18 (4.76) |
| OA | 180.70 (10.40) | 171.32 (15.34) | 179.86 (10.54) |
| PD | 145.36 (9.15) | | 138.84 (6.86) |

Table 7 - Session main effects for PV large target

| PV Learn | B | R1 |
|---|---|---|
| OA and YA | 192.88 (34.68) | 260.43 (40.77) |

**Coefficient of Variance of Peak Velocity (CVPV)**

The coefficient of peak velocity provides a measure of the variability of the initial force impulse (see Tables 8 and 9 for means and CI of CVPV).

**OA and YA.** *Practice.* There was a significant group main effect, the YA group had smaller CVPV than the OA group, $L$ (1) = 7.48, .01 < p > .001. There was also a session main effect; both groups reduced their variability with practice, $L$ (1) = 11.65, .05 < p > .02. *Learning.* There were no significant differences in learning. *Retention.* There was a significant main effect of session. Both the YA and OA groups continued to improve their performance by decreasing their score, $L$ (1) = 10.47, .05 < p > .02.

**PD and OA.** *Practice.* There was a significant session main effect. Each group significantly improved their performance by decreasing CVPV, $L$ (1) = 10.76, .05 < p > .02. *Learning.* Group and session were both significant main effects of learning. The OA had smaller CVPV than the PD group, $L$ (1) = 4.45, .05 < p > .02. Each group decreased CVPV similarly, $L$ (1) = 6.28, .05 < p > .02. *Retention.* Session was a significant main effect. Similar to the YA and OA group, both groups continued to improve CVPV in retention, $L$ (1) = 10.80, .05 < p > .02.

**Summary of CVPV.** The YA and OA, while significantly different from one another in performance, both decreased their mean CVPV with practice and continued to decrease into retention. The PD and OA, comparable to YA and OA, improved during practice, learning, and retention. The two groups were significantly different from one another during learning and retention.

Table 8 - Group main effects for CVPV large target

| CVPV | Practice | Learning |
|---|---|---|
| YA | .11 (.05) | .07 (.02) |
| OA | .10 (.02) | .08 (.01) |
| PD | | .13 (.03) |

Table 9 - Session main effects for CVPV large target

| CVPV Practice | B | P1 | P2 | P3 |
|---|---|---|---|---|
| OA and YA | 0.09 (0.02) | 0.11 (0.07) | 0.07 (0.01) | 0.07 (0.01) |
| PD and OA | 0.14 (0.04) | 0.14 (0.07) | 0.08 (0.01) | 0.1 (0.04) |

| CVPV Learning | B | R1 |
|---|---|---|
| OA and YA | 0.06 (0.01) | 0.07 (0.01) |

| CVPV Retention | R1 | R2 | R3 | R4 |
|---|---|---|---|---|
| OA and YA | 0.06 (0.01) | 0.07 (0.01) | 0.07 0.01) | 0.06 (0.01) |
| PD and OA | 0.07 (0.01) | 0.08 (0.01) | 0.07 (0.01) | 0.06 (0.01) |

**Coefficient of Variance of Time to Peak Velocity (CVTTPV)**

The coefficient of time to peak velocity provides a measure of variability of time to peak velocity within a given number of trials. Means and CI are presented in Table 10 and 11.

**OA and YA.** *Practice.* Group and session were significant main effects. The YA group had a significantly smaller CVTTPV than the OA group, $L\ (1) = 6.39$, $.02 < p > .01$. Each group significantly decreased CVPV with practice, $L\ (1) = 11.71$, $.02 < p > .01$. *Learning.* There was a session trend, $L\ (1) = 4.615$, $.1 < p > .05$. *Retention.* There was a session main effect. Even in retention both groups continued to significantly decrease CVTTPV, $L\ (1) = 11.39$, $.05 < p > .02$. There was also a group trend, $L\ (1) = 2.80$, $.1 < p > .05$.

**PD and OA.** *Practice.* There was a significant session main effect, $L\ (1) = 11.40$, $.05 < p > .02$. *Learning.* There was a session trend, $L\ (1) = 4.81$, $.1 < p > .05$. *Retention.* There was a significant group main effect. The OA had significantly smaller CVTTPV than the PD group, $L\ (1) = 5.80$, $.02 < p > .01$. There was also a session main effect. The PD and OA, similar to the YA and OA group, continued to significantly reduce CVTTPV throughout retention, $L\ (1) = 10.95$, $.05 < p > .02$. There was a trend for a group x session interaction, $L\ (1) = 8.50$, $.1 < p > .05$. Indicating that the two groups improved somewhat different in retention.

**Summary of CVTTPV.** Both, the YA and OA, reduced the mean variability of TTPV with practice, but the YA had lower mean scores than the OA. This may indicate that the YA better preprogram because there is less variability in their timing. The PD and OA groups also reduced their mean CVTTPV score during practice, learning (trend) and retention, indicating an improvement in preprogramming. Only during retention were the two groups different with the PD group exhibiting higher mean scores. This may indicate that PD are not able to continue to improve preprogramming without practice to the degree of OA.

Table 10 - Group main effects for CVTTPV large target

| CVTTPV | Practice | Retention |
|---|---|---|
| YA | .09 (.02) | |
| OA | .06 (.02) | .07 (.02) |
| PD | | .09 (.02) |

Table 11 - Session main effects for CVTTPV large target

| CVTTPV Practice | B | P1 | P2 | P3 |
|---|---|---|---|---|
| OA and YA | 0.07 (0.02) | 0.1 (0.04) | 0.07 (0.03) | 0.06 (0.01) |
| PD and OA | 0.11 (0.02) | 0.12 (0.03) | 0.09 (0.02) | 0.08 (0.02) |

| CVTTPV Retention | R1 | R2 | R3 | R4 |
|---|---|---|---|---|
| OA and YA | 0.08 (0.05) | 0.06 (0.03) | 0.05 (0.01) | 0.04 (0.01) |
| PD and OA | 0.09 (0.05) | 0.09 (0.03) | 0.07 (0.02) | 0.06 (0.02) |

## Small Target

### Movement Time (MT)

Table 12 displays means and CI of MT.

**OA and YA.** *Practice.* There was a group significant main effect. The YA had significantly faster MT than that of OA, $L$ (1) = 4.20, .05 < p > .02. *Learning.* There was a group trend, $L$ (1) = 3.456, .01 < p > .001, for the YA to have faster MT than the OA. *Retention.* There were no significant differences in retention. (Session p > .9 and group p > .2.)

**PD and OA.** *Practice.* There were no significant differences in practice. *Learning.* There was a significant group main effect, $L$ (1) = 6.36, .02 < p > .01, indicating that the OA were faster during learning than the PD group. *Retention.* Group was a main effect in retention, $L$ (1) = 4.1, .05 < p > .02. The OA group maintained faster MT compared to the PD group.

**Summary of MT.** The YA and OA groups did not reduce mean MT with practice or learning. However, there was a significant group difference in practice and a trend in group differences in learning. This may imply an aging effect, while neither group changed performance, the OA was consistently slower than the YA group. The PD and OA groups were significantly different during learning and retention, but neither group changed performance.

Table 12 - Group main effects for MT small target

| MT | Practice | Learning | Retention |
|---|---|---|---|
| YA | 492.74 (9.17) | 557.23 (11.20) | |
| OA | 557.23 (6.56) | 551.33 (9.53) | 517.43 (6.24) |
| PD | | 635.45 (16.24) | 616.4 (2.95) |

**Time to Peak Velocity (TTPV)**

**OA and YA.** *Practice.* There was group trend, *L* (1) = 3.76, .1 < p > .05, for the YA to be faster than the OA. (Session p > .2.) *Learning.* There was a session trend, *L* (1) = 6.83, .1 < p > .05. (Group p > .1.) *Retention.* There were no significant differences in retention. (Session p > .5 and group p > .1.)

**PD and OA.** *Practice.* There was a significant session main effect during practice, *L* (1) = 10.96, .05 < p > .02. There was a group trend, *L* (1) = 3.79, .1 < p > .05. *Learning.* There was a session trend during learning, *L* (1) = 7.72, .1 < p > .05, and a group trend, *L* (1) = 4.49, .1 < p > .05. *Retention.* There was a group trend during retention, L (1) = 3.26, .1 < p > .05. (Session p > .2.)

**Summary of TTPV.** Time to peak velocity does not appear to be a sensitive measure of a precise movement using online feedback, as expected.

**Time After Peak Velocity (TAPV)**

**OA and YA.** *Practice.* There was a group trend, *L* (1) = 2.73, .1 < p > .05 with the YA group exhibiting less time. *Learning.* There were no significant differences in learning. *Retention.* There were no significant differences in retention.

**PD and OA.** *Practice.* There were no significant differences in practice. (Session $p > .7$ and group $p > .2$) *Learning.* There was a group trend, $L(1) = 3.31$, $.1 < p > .05$. *Retention.* There was a group trend, $L(1) = 3.08$, $.1 < p > .05$.

**Summary of TAPV.** The group trends indicate that the YA group spent less mean time in online control where the PD group spent more time.

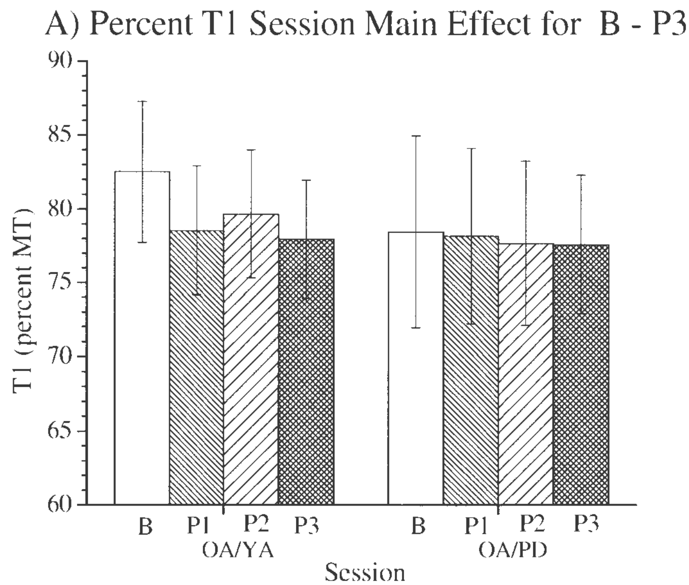
**Percent of Primary Submovement in Movement Time (%T1)**

Figure 9 displays means and CI of %T1.

**OA and YA.** *Practice.* There was a session main effect for practice, $L(1) = 10.62$, $.05 < p > .02$, each group decreased %T1. *Learning.* There was a trend for session, $L = 5.67$, $.1 < p > .05$. *Retention.* There was a session main effect, $L(1) = 10.77$, $.05 < p > .02$. There was also a group trend, $L(1) = 3.16$, $.1 < p > .05$.

**PD and OA.** *Practice.* There was a session main effect for practice, $L(1) = 11.05$, $.05 < p > .02$, groups decreased %T1. *Learning.* There was a session trend, $L(1) = 5.04$, $.1 < p > .05$. *Retention.* Session was a significant main effect. Both groups decreased %T1, $L(1) = 11.14$, $.05 < p > .02$. There was also a group trend, $L(1) = 3.39$, $.1 < p > .05$.

**Summary of %T1.** It appears that all groups changed their movement characteristics with practice by decreasing the mean time spent in T1 in the small target. This finding is contrary to previous research. This change in movement was not retained.



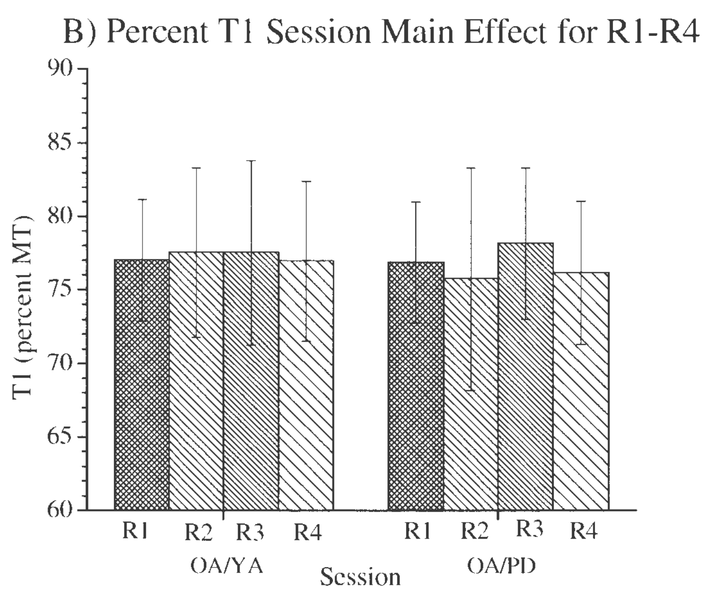




Figure 9 – Session main effects for %T1

**Zero Acceleration Crossings**

**<u>OA and YA.</u>** *Practice.* There were no significant differences. (Session $p > .7$ and group $p > .8$.) *Learning.* There were no significant differences. (Session $p > .95$ and group $p > .5$) *Retention.* There were no significant differences. (Session $p > .99$ and group $p > .8$.)

**<u>PD and OA.</u>** *Practice.* There were no significant differences. (Session $p > .7$ and group $p > .1$.) *Learning.* There was a significant group x session interaction, $L$ (1) = 6.23, $.05 < p > .02$, with the PD group decreasing their number of crossings while the OA group increased their number of crossings. *Retention.* There were no significant differences. (Session $p > .8$ and group $p > .1$.)

**<u>Summary of Zero Acceleration Crossings.</u>** The only difference in zero acceleration crossings was found in the OA and PD groups during learning.

**Peak Velocity (PV)**

Tables 13 and 14 displays PV means and CI.

**<u>OA and YA.</u>** *Practice.* There was a group main effect, $L$ (1) = 5.31, $.05 < p > .02$, the YA had a higher PV than the OA group. There was also a session trend, $L$ (1) = 7.98, $.1 < p > .05$. *Learning.* There was a group main effect, the YA had a higher PV than the OA group, $L$ (1) = 5.31, $.05 < p > .02$. Session was also a main effect, each group increased PV during learning, $L$ (1) = 6.46, $.05 < p > .02$. *Retention.* Group was a significant main effect, the YA continued to have a higher PV, $L$ (1) = 4,59, $.05 < p > .02$.

**<u>PD and OA.</u>** *Practice.* There were no significant differences in practice. There were differences in the two groups' performance. (Session $p > .3$ and group $p > .8$.) *Learning.* Again, there were no significant differences in learning. (Session $p > .5$ and group $p > .5$.)

*Retention.* There were no significant differences in retention. (Session $p > .2$ and group $p > .98$.)

**Summary of PV.** The YA group consistently had a higher averaged PV than the OA group. Each group had a higher PV during learning, but both groups were not able to retain the improvement. The PD and OA groups were not significantly different from one another in any performance. These groups did not significantly change their mean PV. This suggests that the group differences observed between the YA and the OA are the result of aging as these groups increased mean PV during learning. However, similar to the large target a ranked repeated measures ANOVA was conducted on only the OA group during learning. The OA group did not have a significant session effect. This group did not increase mean PV like the YA group.

Table 13 - Group main effects for PV small target

| PV | Practice | Learning | Retention |
|---|---|---|---|
| YA | 177.12 (4.60) | 177.89 (10.00) | 185.46 (3.21) |
| OA | 110.43 (5.64) | 108.59 (7.67) | 114.75 (8.58) |

Table 14 - Session main effects for PV small target

| PV Learning | B | R1 |
|---|---|---|
| OA and YA | 130.04 (27.93) | 156.44 (35.41) |

**Coefficient of Variance of Peak Velocity (CVPV)**

Table 16 displays CVPV means and CI.

**OA and YA.** *Practice.* There was a session main effect, $L\ (1) = 11.15$, $.05 < p > .02$, each group decreased CVPV. *Learning.* There was a session trend, $L\ (1) = 5.12$, $.1 < p > .05$.

*Retention.* There was a session main effect, *L* (1) = 10.66, .05 < p > .02. Each group continued to reduce CVPV in retention.

**PD and OA.** *Practice.* There was a session main effect in practice, *L* (1) = 11.86, .05 < p > .02, both groups decreased CVPV. *Learning.* There was a session main effect for learning. Groups decreased CVPV, *L* (1) = 6.62, .05 < p > .02. *Retention.* There was a session effect in retention, *L* (1) = 10.69, .05 < p > .02. Both groups continued to decrease CVPV throughout retention.

**Summary of CVPV.** Throughout the experiment all groups significantly decreased mean CVPV, even through retention. This indicates that all groups decrease mean variability in their ability to produce force regardless of practicing the movement. There were no group differences, suggesting that this measurement is not subject to aging or Parkinson's disease.

Table 16 - Session main effects for CVPV small target

| CVPV Practice | B | P1 | P2 | P3 |
|---|---|---|---|---|
| OA and YA | 0.09 (0.02) | 0.1 (0.05) | 0.08 (0.01) | 0.09 (0.02) |
| PD and OA | 0.09 (0.03) | 0.1 (0.06) | 0.09 (0.02) | 0.09 (0.02) |

| CVPV Learning | B | R1 |
|---|---|---|
| PD and OA | 0.09 (0.03) | 0.09 (0.02) |

| CVPV Retention | R1 | R2 | R3 | R4 |
|---|---|---|---|---|
| OA and YA | 0.1 (0.02) | 0.09 (0.02) | 0.08 (0.01) | 0.08 (0.01) |
| PD and OA | 0.09 (0.02) | 0.09 (0.01) | 0.09 (0.03) | 0.08 (0.01) |

**Coefficient of Variance of Time to Peak Velocity (CVTTPV)**

Table 17 displays CVTTPV means and CI.

**OA and YA.** *Practice.* There was a significant session main effect, $L$ (1) = 11.09, .05 < p > .02. Each group significantly decreased CVTTPV with practice. *Learning.* There was a significant session main effect, $L$ (1) = 6.70, .01 < p > .001. *Retention.* There was a session main effect, $L$ (1) = 10.91, .05 < p > .02, each group continued to decrease CVTTPV in retention.

**PD and OA.** *Practice.* There was a significant session main effect, $L$ (1) = 11.10, .05 < p > .02. *Learning.* There was a session trend, $L$ (1) = 5.85, .1 < p > .05. *Retention.* There was a significant session main effect. Both groups continued to reduce CVTTPV throughout retention, $L$ (1) = 11.22, .05 < p > .02.

**Summary of CVTTPV.** Similar to CVPV, all three groups throughout the experiment reduce their mean CVTTPV, and these reductions were maintained across retention.

Table 17 - Session main effects for CVTTPV small target

| CVTTPV Practice | B | P1 | P2 | P3 |
|---|---|---|---|---|
| OA and YA | 0.09 (0.02) | 0.07 (0.01) | 0.07 (0.01) | 0.08 (0.04) |
| PD and OA | 0.12 (0.04) | 0.07 (0.02) | 0.09 (0.02) | 0.09 (0.02) |

| CVTTPV Learning | B | R1 |
|---|---|---|
| OA and YA | 0.09 (0.02) | 0.08 (0.02) |

| CVTTPV Retention | R1 | R2 | R3 | R4 |
|---|---|---|---|---|
| OA and YA | 0.08 (0.02) | 0.08 (0.02) | 0.08 (0.02) | 0.07 (0.02) |
| PD and OA | 0.09 (0.02) | 0.09 (0.02) | 0.09 (0.04) | 0.07 (0.01) |

**Overall Summary**- An overall summary of the results are shown in Table 18. Again, practice is considered the mean values of B, P1, P2, and P3. Learning is considered the mean values of B and R1. Retention is considered the mean values of R1, R2, R3, and R4. Significance levels are given at $p < .05$ and $p < .02$. The large target findings are on the left of the table and the small target on the right.

Table 18 - Significant main effects for all dependent variables

| | Large Target | | | | | | | Small Target | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Group Main Effects | | | Session Main Effects | | | | Group Main Effects | | | Session Main Effects | | |
| | P | L | R | P | L | R | | P | L | R | P | L | R |
| MT YA/OA | ** | ** | ** | * | ** | | | * | | | | | |
| MT OA/PD | ** | ** | ** | * | ** | | | | ** | * | | | |
| TTPV YA/OA | ** | ** | ** | | ** | | | | | | * | | |
| TTPV OA/PD | | * | | * | * | | | | | | | | |
| TAPV YA/OA | ** | ** | ** | ** | ** | | | | | | | | |
| TAPV OA/PD | ** | ** | ** | ** | * | | | | | | | | |
| %T1 YA/OA | | | | * | * | * | | | | | * | | * |
| %T1 OA/PD | * | * | ** | * | * | ** | | | | | * | | * |
| Zero X YA/OA | | | | | | | | | | | | | |
| Zero X OA/PD | ** | | ** | | | | | | | | | | |
| PV YA/OA | ** | ** | ** | | ** | | | * | * | * | | * | |
| PV OA/PD | * | ** | | | | | | | | | | | |
| cvPV YA/OA | ** | | | * | | * | | | | | * | | * |
| cvPV OA/PD | | * | | * | * | * | | | | | * | * | * |
| cvTTPV YA/OA | ** | | | ** | | * | | | | | * | ** | * |
| cvTTPV OA/PD | | | ** | * | | * | | | | | * | | * |

*= p < .05, ** = p <.02

## DISCUSSION

The purpose of this study was to investigate the effects of long-term practice of a discrete aiming movement in three groups: YA, OA, and PD. The effects of aging were examined by comparing YA vs. OA, and the effects of PD were examined by comparing OA to PD. The ability of these groups to perform ballistic and online control was addressed by using a high and low index of difficulty task.

There were four goals for this experiment. The first goal was to investigate if the changes that occur during the practice of large and small rapid aiming in young adults were retained up to three weeks. The second goal was to investigate if older adults, who were provided distributed practice across weeks, would exhibit increased preprogramming (i.e., increased percentage of total time in T1) of rapid aiming and use online feedback more efficiently (i.e., decreased zero acceleration crossings). A third goal was to explore if people with PD would perform large and small rapid aiming similarly to age-match controls after distributed practice, or if the disruption of Parkinson's is in addition to aging. The fourth goal was to assess if improvements were retained in older adults and Parkinson's patients.

As hypothesized, with practice the YA group decreased MT, decreasing both TTPV and TAPV. They also increased time spent in the first submovement and increased PV. Interestingly, they did retain their speed of movement, but did not retain a greater reliance on T1 after practice and augmented feedback were removed. The OA group exhibited similar changes with practice and in retention. The average of the OA and YA group increased PV and decreased CVPV, showing improvement of ballistic control. Their average increase in T1 with practice is different from previous research (Pratt et al., 1994). The results from the present study indicate that distributed practice may aid older adults in making this shift.

Another difference between the previous studies and this study is that the accuracy requirements were very low for the large target, thus encouraging a shift towards reliance on ballistic control.

Even with practice, there were still group differences between the YA and OA groups. One possibility for the difference in movement strategies used by the groups may have to do with the nature of the task. In many of the studies investigating rapid aiming a two-dimensional movement was used, such as arm pointing (Abrams & Pratt, 1993; Pratt & Abrams, 1996), elbow flexion and extension (Khan & Franks 2000, 2003), or wrist rotation (Abrams & Pratt, 1993, Pratt et al., 1996). In these studies participants were allowed to overshoot and continue the movement to correct the error. However, in the present experiment participants were allowed to hit the target with as much force as they desired as long as they maintained contact with the target. It appears that the YA group used this feature to their advantage; by hitting the target harder they spent less time on the movement.

In contrast to the results for the large target, there were minimal changes with practice in the small target condition. Neither the OA nor YA groups exhibited a decrease in MT, TTPV or TAPV with practice. Interestingly, however, percent of time in the first submovement did increase in a similar manner for both groups, but again this shift was not retained. Both groups also increased PV, decreased CVPV and CVTTPV and retained this reduction in variability.

The PD group moved more slowly than their age-matched peers, as expected. The primary locus of this slowing was in TAPV. The PD group also exhibited more submovments, which is consistent with more reliance on online control. Both the OA and PD groups decreased TAPV with practice, and retained this across three weeks of retention. Both groups did improve their overall ballistic control of discrete aiming by reducing MT, CVPV, TTPV, CVTTPV, and TAPV. These improvements suggest that OA and PD are able to improve preprogramming for ballistic movements. It is also apparent that PD and OA use comparable movement strategies as YA, as improvements are similar. It is evident that Parkinson's disease does affect aspects of movement. Peak velocity values for the OA and PD groups were both significantly less than the YA group.

There were few significant differences between the OA and PD groups in the small target condition. Like the other groups, the PD did not exhibit a significant reduction in MT, decreasing their reliance on the first submovement. However, like the other groups, this change was not retained. They became less variable in force production and timing, as evidenced by a decrease in CVPV and CVTTPV; this indicates that the noisiness of the force impulse can be reduced with practice.

The expectation for retention was that the YA and OA groups would retain changes across the three week interval and that the PD group would not. Of the variables that did improve with practice, only time spent in the first submovement improved during practice in both conditions by all groups, but was not retained by any of the groups. The small target did not show as much improvement in all groups as the large target. This finding suggests that for conditions with a high index of difficulty, either more practice trials are needed to improve performance or very high precision tasks cannot be improved to the degree of a low index of difficulty task.

There were three variables in the large condition, MT, TTPV, and TAPV, which were in improved with practice in all groups and retained. The current finding that all groups can learn and improve a discrete aiming movement over three weeks of practice and three weeks of retention is somewhat unique. Only two studies (Khan & Franks, 2000, 2003) explored practice with more than 1000 trials of a discrete aiming movement. However, this practice took place over just one week. No research to date has investigated long-term practice and retention up to three weeks.

Again, for most dependent variables all groups improved and learned the movement in the large target, but the mechanisms providing for the movement improvement were different among the groups. The YA were able to improve their movement through preprogramming, observed by an increased percentage of time to peak velocity and greater peak velocity. The PD improved through an overall faster primary submovement. Although much of the primary submovement is preprogrammed, after reaching peak velocity some online information is utilized to complete the first submovement (Khan & Franks, 2000). The key finding that Parkinson's patients can learn and retain their improvement with practice and retention has important implications for the clinical setting. This experiment gives support for Parkinson's patients to receive physical therapy as a treatment to recover lost function.

One of the goals of the experiment was to examine if the reduced dopamine in OA would inhibit their ability to produce force and create pseudo-bradykinetic characteristics. In other words, were the movement degradations observed in older adults the result of general aging or decreased dopamine? It appears that the answer may be a combination of both. It is clear that the older groups have a hard limit to the amount of peak velocity produced indicating an aging effect. However, the OA group did not display the same level of values as the PD group in most variables.

One of the goals of the experiment was to examine if Parkinson's patients reduce the bradykinetic effects of their disease. Overall, the Parkinson's patients had the slowest MT, lowest PV, and lowest %T1. However, this group was able to improve their performance and learn the movement equal to that of their neurologically healthy peers, in most cases, after one or two weeks of practice. After three weeks of practice and three weeks of retention the Parkinson's patients produced faster MT and had a faster TTPV than their baseline. As stated above, this group was able to retain these improvements throughout the experiment. These observations suggest that bradykinetic effects reduce in Parkinson's patients with practice.

Sample size was a limitation of this study. The small sample size in this experiment resulted in less powerful statistics. There was no hardship in obtaining members for the YA group or for the OA group. However, it was difficult to recruit individuals with Parkinson's disease to participate in this study. Most persons with Parkinson's disease had a desire to take part in this study; however, other issues such as transportation made participation impossible. Additionally, central Iowa is considered rural; thereby, there are in less people in general. This results in less people with Parkinson's disease. Although Ames is close to Des Moines, Iowa, the distance traveled by a Parkinson's patient takes more of an effort than a neurologically healthy individual.

## CONCLUSION

The present experiment supports practice of rapid aiming as a mechanism for improvement of the movement in all three groups tested. The degree and the processes by which these groups improve are diverse, as expected. Further, this study coincides with past research on the mechanisms by which young adults improve their rapid aiming movement. But, as stated above less is understood about how older adults improve rapid aiming movements.

Walker et al. (1997) stated that with aging people place a greater priority on accuracy, have less efficient feedback processing in closed-loop control, increased noise-to-force ratio, and decreased ability to produce force. Although not all of these were seen in the current study, the results of the older adult movement support the later three factors. Along with observing these degradations in this study, it was also found that older adults are capable of improving their movement. In a few cases this improvement was to the same degree as young adults to the same degree.

The findings of this experiment indicate that young adults, older adults, and Parkinson's patients are able to learn and retain a discrete aiming movement. However, the mechanisms used and exploited are vastly different between the young adults and the other two groups. Young adults take advantage of their ability to produce high peak velocity to execute their movement. Older adults and Parkinson's patients reduce their overall movement, but do not rely on a ballistic movement.

Importantly, Parkinson's patients were able to learn and retain a discrete aiming movement. The robustness of this finding is unknown. It is unclear if the discrete aiming task explored in this experiment would transfer to other tasks. In other words, could Parkinson's patients learn and retain all movements or only the discrete aiming task in this experiment. However, this study supports therapy for Parkinson's patients as a means of improving quality of life and restore function.

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